

REUSABLE SOFTWARE ARCHITECTURE FOR SPACECRAFT

Benjamin Moultrie, Ph.D.

**Lockheed Martin Corporation
Lockheed Martin Astronautics
P.O. Box 179
Denver, CO 80201-0179**

April 1998

Final Report

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION IS UNLIMITED.

19980707 222



**AIR FORCE RESEARCH LABORATORY
Space Vehicles Directorate
3550 Aberdeen Ave SE
AIR FORCE MATERIEL COMMAND
KIRTLAND AIR FORCE BASE, NM 87117-5776**

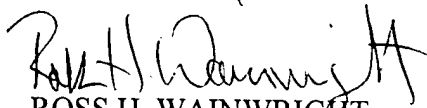
Using Government drawings, specifications, or other data included in this document for any purpose other than Government procurement does not in any way obligate the U.S. Government. The fact that the Government formulated or supplied the drawings, specifications, or other data, does not license the holder or any other person or corporation; or convey any rights or permission to manufacture, use, or sell any patented invention that may relate to them.

This report has been reviewed by the Public Affairs Office and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nationals.

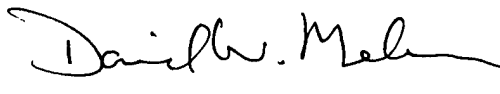
If you change your address, wish to be removed from this mailing list, or your organization no longer employs the addressee, please notify AFRL/VSSS, 3550 Aberdeen Ave SE, Kirtland AFB, NM 87117-5776.


Do not return copies of this report unless contractual obligations or notice on a specific document requires its return.

This report has been approved for publication.


ROSS H. WAINWRIGHT
Project Manager

FOR THE COMMANDER


L. KEVIN SLIMAK
Chief, Surveillance and Controls Division


BRUCE A. THIEMAN, Col, USAF
Deputy Director, Space Vehicles

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE

07 April 1998

3. REPORT TYPE AND DATES COVERED

Final;
24 March 1994 - 04 April 1998

4. TITLE AND SUBTITLE

Reusable Software Architecture for Spacecraft

5. FUNDING NUMBERS

C: F29601-94-C-0114
PE: 78026F
PR: 2181
TA: TB
WU: AB

6. AUTHOR(S)

Benjamin Moultrie, Ph.D.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Lockheed Martin Corporation
P. O. Box 179
Denver, CO 80201

8. PERFORMING ORGANIZATION
REPORT NUMBER

MCR-94-518

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Air Force Research Laboratory
Space Vehicles Directorate
3550 Aberdeen Avenue SE
Kirtland AFB, NM 87117-5776

10. SPONSORING/MONITORING
AGENCY REPORT NUMBER

AFRL-VS-PS-TR-1998-1042

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION IS UNLIMITED

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

This report provides a comprehensive overview of a tool that incorporates the products of spacecraft domain engineering to help automate the flight software application engineering process. The tool—called the "Workbench"—was developed under the Reusable Software Architecture for Spacecraft (RSAS) contract for the Air Force Research Laboratory's Phillips Research Site. It incorporates a domain decision model that is used to determine the selection and possible tailoring of reusable components for the instantiation of domain applications. Workbench users specify application attributes via a graphical interface. They are assisted by context-sensitive on-line help information that is available through a Web browser such as Netscape®.

Although the Workbench was developed to simplify and automate the reuse of spacecraft flight software, it facilitates application engineering in any product-line environment where the reuse of assets is governed by a complex decision-making process. It can be adapted for non-spacecraft applications where domain engineering tasks have been completed.

14. SUBJECT TERMS

spacecraft, domain engineering, application engineering, flight software,
software components, decision model, reuse

15. NUMBER OF PAGES

18

16. PRICE CODE

17. SECURITY CLASSIFICATION
OF REPORT

UNCLASSIFIED

18. SECURITY CLASSIFICATION
OF THIS PAGE

UNCLASSIFIED

19. SECURITY CLASSIFICATION
OF ABSTRACT

UNCLASSIFIED

20. LIMITATION OF ABSTRACT

UNLIMITED

(This Page Left Intentionally Blank)

Executive Summary

This report provides an overview of the application engineering Workbench developed by Lockheed Martin Astronautics under the Reusable Software Architecture for Spacecraft (RSAS) contract to the Air Force Research Laboratory (AFRL) Space Vehicles Directorate. The RSAS Workbench was developed on a contract that had as its primary objective the creation of an application engineering tool for the spacecraft flight software domain. It incorporates a domain decision model that is used to determine the selection and possible tailoring of reusable components for the instantiation of domain applications. Workbench users specify application attributes via a graphical interface. They are assisted by context-sensitive on-line help information that is available through a Web browser such as Netscape®.

The RSAS Workbench development effort benefited from data developed in a concurrent Independent Research and Development (IR&D) project that the contractor, Lockheed Martin Astronautics (LMA), was conducting at the time. The IR&D focused on the development of reusable flight software components. Domain engineering was performed for three-axis stabilized spacecraft. This activity resulted in a generic spacecraft system architecture, reusable software components, and an associated decision model that were subsequently used in the RSAS Workbench.

The Workbench was installed at the AFRL Space Vehicles Directorate ready to incorporate software components beyond those provided through LMA's IR&D effort. In addition, it was installed in LMA's Spacecraft Technology Center II as well as in the Lockheed Martin Missiles and Space (LMMS) Spacecraft Product Center in Sunnyvale where in December 1997 it was used to support a successful demonstration of an application engineering process for the SBIRS (Space-Based Infrared System) Program.

Although the Workbench was developed to simplify and automate the reuse of spacecraft flight software, it facilitates application engineering in any product-line environment where the reuse of assets is governed by a complex decision-making process. It can be adapted for non-spacecraft applications where domain engineering tasks have been completed. The Workbench is installed at the AFRL Space Vehicles Directorate as well as at LMA in Denver and LMMS in Sunnyvale.

(This Page Left Intentionally Blank)

TABLE OF CONTENTS

SECTION	PAGE
INTRODUCTION.....	1
WORKBENCH BACKGROUND.....	1
WORKBENCH DESCRIPTION.....	2
DOMAIN ADAPTATION.....	8
SUMMARY.....	9

LIST OF FIGURES

FIGURE	PAGE
FIGURE 1 WORKBENCH SESSION CONSTITUENTS.....	3
FIGURE 2 RSAS MISSION SELECTION SCREEN	4
FIGURE 3 RSAS MISSION EDITOR SCREEN	5
FIGURE 4 RSAS PLATFORM EDITOR SCREEN	5
FIGURE 5 RSAS DECISION MODEL ROOT SCREEN	6
FIGURE 6 EXAMPLE OF A DECISION MODEL PARAMETER SCREEN.....	6
FIGURE 7 RSAS COMPONENT GENERATION SCREEN.....	7
FIGURE 8 WORKBENCH SESSION PROCESS FLOW.....	8

LIST OF TABLES

TABLE	PAGE
TABLE 1 FLIGHT SYSTEMS SURVEYED	2
TABLE 2 DOMAIN ADAPTATION COST ESTIMATES	8
TABLE 3 WORKBENCH HOST ENVIRONMENT.....	9

Acknowledgements

The Workbench is the product of a small team of very talented software engineers at Lockheed Martin Astronautics. The team comprised Eric Chen, Karen Hover, and Monte Ratajczyk who was the technical leader. The successful development of the Workbench could not have been achieved without the team's collective commitment to a common goal, and the individual sacrifices of team members.

Mr. Ross Wainwright—Air Force Research Laboratory's Manager for the RSAS contract—is worthy of special thanks. He was always willing to support the impromptu technical exchanges, "brain storming" sessions, and prototyping exercises that determined the direction of the RSAS Workbench. His collaborative approach was integral to the successful development of the Workbench.

Introduction

The establishment of a product-line engineering environment is viewed with increasing interest as the solution to the achievement of cost and schedule reductions for the development of complex systems. Realization of the expected benefits in this approach requires the performance of two major activities. The first activity—called “domain engineering”—involves the in-depth analysis and modeling of the domain with the resulting development of standardized components that are used to produce (“instantiate”) specific applications. The second activity—called “application engineering”—involves the systematic use of processes and tools to instantiate domain applications based on specific mission needs and requirements. The domain engineering activity produces a generic domain architecture, compatible generic application components that can be tailored in pre-defined ways, and a decision model that captures the expertise and lessons learned needed to instantiate an application. Domain engineering has been the dominant focus of efforts to establish product-lines within the aerospace industry and has successfully produced numerous inventories of reusable components for both hardware and software applications. In comparison, efforts in application engineering are at an early stage of maturation.

This report provides a comprehensive overview of a tool—called the “Workbench”—that significantly advances the state-of-the-art for application engineering in a reuse-based development environment. The Workbench incorporates a domain decision model that captures knowledge from domain experts. This intelligence—developed during domain engineering—enables the Workbench to select and tailor reusable components needed to instantiate applications. Domain lessons learned can be incorporated as decisions, thereby automating their use in application engineering. The tool guides the user through the decision-making process by means of user-friendly graphical screens, and captures the user’s decisions for later use. It can be used to support programs from early application prototyping through final application production.

A discussion of the Workbench background is presented in the next section of this report. This is followed by a description of Workbench in terms of its current application domain and features. A description of domain adaptation process and cost is presented next. The final section herein provides a summary of this report.

Workbench Background

Under a four-year research and development contract that concluded successfully in April 1998, Lockheed Martin Astronautics (LMA) developed a Workbench tool that facilitates application engineering in a product-line environment. This work was performed under the Reusable Software Architecture for Spacecraft (RSAS) contract to the Air Force Research Laboratory (AFRL) Space Vehicles Directorate. It had as its key objective the development and implementation of technology that could simplify software reuse and reduce the associated cost for the development of spacecraft flight applications. Workbench technology is not domain specific although it was developed for spacecraft applications. It can facilitate recurring application engineering in any development environment where the intelligent reuse of assets is governed by a complex decision-making process.

The RSAS Workbench development effort benefited from data developed in a concurrent Independent Research and Development (IR&D) project that LMA was conducting at the time. The IR&D focused on the development of reusable flight software components. Domain engineering was performed for three-axis stabilized spacecraft. As part of this activity, a survey was conducted to gather spacecraft system requirements from seven independent flight projects spanning defense, civil, and commercial systems. The survey included an examination of academic approaches to flight system specification and design, and numerous discussions with subsystem experts. The resulting flight subsystem requirements were captured in a Functional Requirements Matrix (FRM). The diversity of projects surveyed, and the accompanying research, provided a comprehensive view of common flight system requirements as well as differences among flight systems. The seven flight systems included in the survey are identified in Table 1.

TABLE 1 FLIGHT SYSTEMS SURVEYED

Program Name	Customer	Market Sector	Orbit Type	Mission Description
GE-1 (A2100)	GE Americom	Commercial	Geostationary	Communications
Magellan	NASA-JPL	Civil	Interplanetary/ Low Altitude	Scientific
Brilliant Pebbles	SDIO	Defense	Classified	Missile Defense
Lunar Resource Mapper	NASA-JPL	Civil	Interplanetary/ Low Altitude	Scientific
Earth Observation System	NASA-Goddard	Civil	Low Earth Orbit	Remote Sensing /Earth Science
Brilliant Eyes	SDIO	Defense	Classified	Remote Sensing
P-81	Classified	Defense	Classified	Classified

The typical spacecraft system consists of eight subsystems: Guidance, Navigation and Control; Communications; Command and Data Handling; Electrical Power; Thermal; Structures and Mechanisms; Propulsion; Payload. This general allocation of system functionality and the FRM were used as inputs to the detailed object-oriented domain analysis and modeling tasks performed by the IR&D. These tasks supported the identification of capabilities needed in an application engineering tool. In addition, they resulted in a generic spacecraft system architecture, reusable software components, and an associated decision model that were subsequently used in the RSAS Workbench.

The Workbench was installed at the AFRL Space Vehicles Directorate ready to incorporate software components beyond those provided through the LMA IR&D effort. In addition, it was installed in LMA's Spacecraft Technology Center II as well as in the Lockheed Martin Missiles and Space (LMMS) Spacecraft Product Center in Sunnyvale where in December 1997 it was used to support a successful demonstration of an application engineering process for the SBIRS (Space-Based Infrared System) Program.

Workbench Description

The Workbench consists of a graphical user interface (GUI), an application that interfaces with an underlying Oracle® database, and an ASCII text editing tool (TRF-2) developed by Software Architecture and Engineering, Inc. It mechanizes the domain decision model and can incorporate the adaptable components that are developed during domain engineering. At a top level, the Workbench can be described in terms of capabilities to

1. automate the collection and evaluation of user domain decisions and application specifications;
2. select the components that provide the needed application functionality;
3. tailor ASCII text-based components as needed to satisfy application requirements.

The Workbench makes the component selection process and tailoring for application instantiation virtually transparent to the user. During a Workbench session, the user is guided through a series of graphical screens that gather application context information, descriptions of needed application functionality, and user selections for Workbench outputs. Constituents of a Workbench session are illustrated in Figure 1.

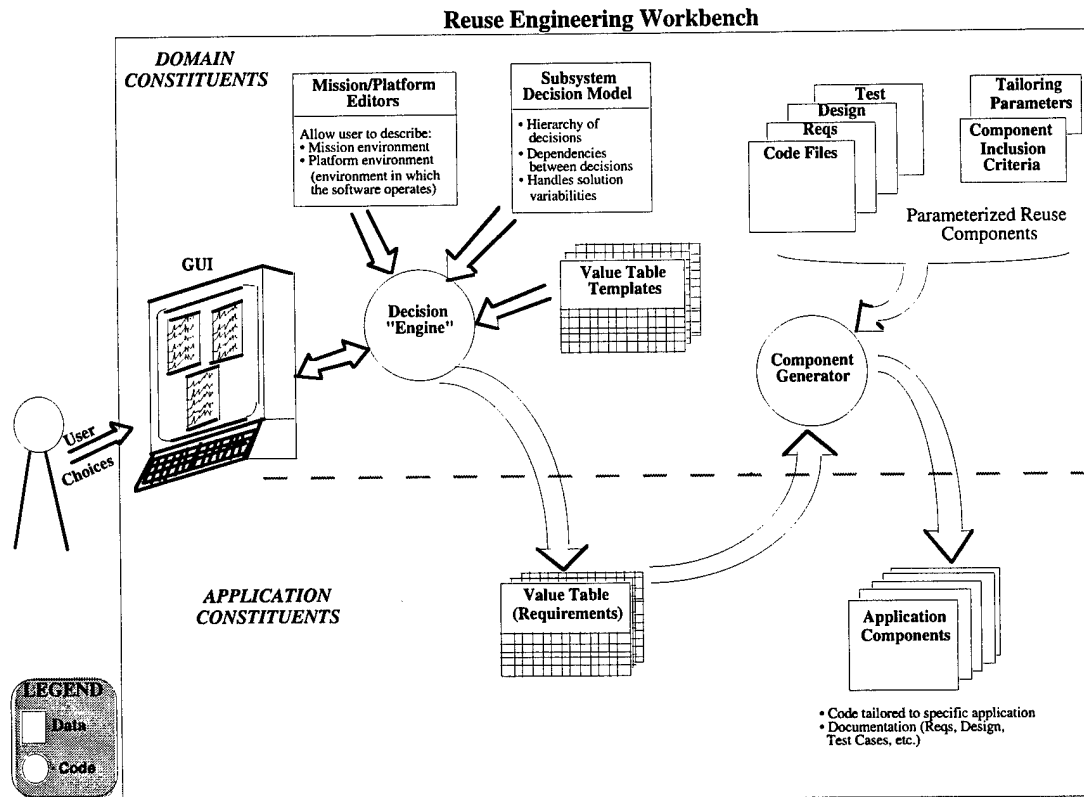


FIGURE 1 WORKBENCH SESSION CONSTITUENTS

LMA and LMMS installations of the Workbench are configured to support application engineering in spacecraft flight software development environments. All current Workbench installations are functionally identical. (Lockheed Martin used internal funding to modify the decision model structure in its Workbench installations to support domain components developed by LMMS's Spacecraft Product Center.) At any time during a Workbench session, the user can access on-line context-sensitive help to obtain explanations of Workbench features. Help information is viewed using a World Wide Web browser such as Netscape®.

On entry into the RSAS Workbench, the user is presented with a Mission Selection screen as depicted in Figure 2.

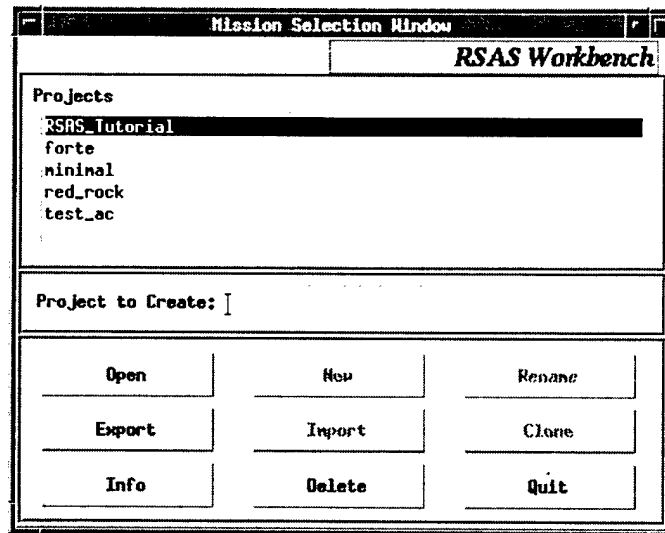


FIGURE 2 RSAS MISSION SELECTION SCREEN

The Mission Selection screen provides buttons for

- creating a new mission,
- opening an existing mission,
- importing and exporting a mission,
- cloning a new mission from an existing mission,
- deleting a mission, and
- renaming a mission.

Once the selection of a mission option has been selected, the user moves to the Mission Editor to establish the mission context. The Mission Editor is used to specify the external environment in which spacecraft operate; a constellation of spacecraft is permitted. Features include a palette of tools for specifying spacecraft external environment (e.g., celestial bodies and ground stations), an annotation tool, and object detail capture capability. Detail information that can be provided by the user includes the specification of values for physical attributes such as gravity fields. Default values are defined as required. All bit-mapped graphics are replaceable by Workbench users. The Mission Editor screen is shown in Figure 3.

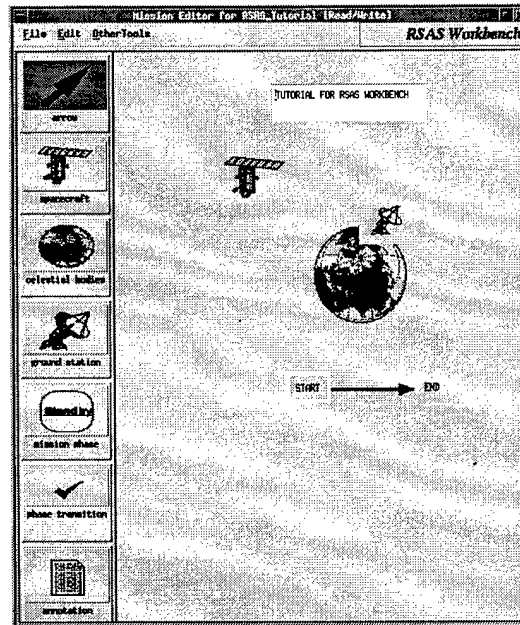


FIGURE 3 RSAS MISSION EDITOR SCREEN

Each spacecraft created in the Mission Editor can be expanded to access a screen in which the user describes the flight software computational environment. This screen—called the Platform Editor—is shown in Figure 4 for the RSAS Workbench implementation.

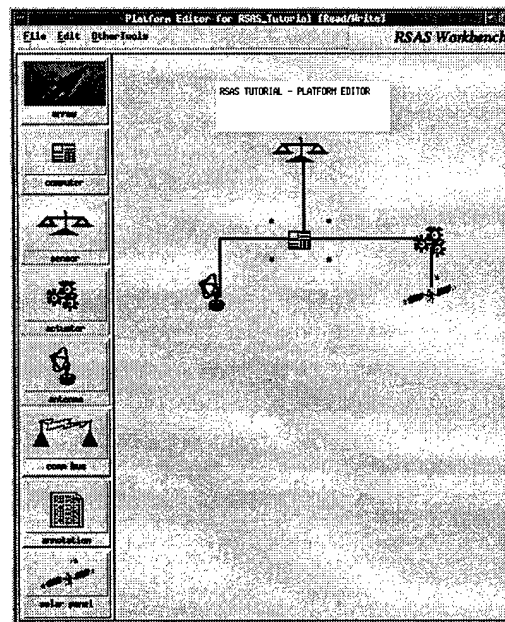


FIGURE 4 RSAS PLATFORM EDITOR SCREEN

The Platform Editor contains a palette of tools for describing the hardware context for software. The user can select hardware devices from a pre-defined collection of computers, sensors, actuators, and communication buses. Annotation sheets can be attached to devices to capture special information. The

palette includes a tool that is used to allocated subsystem software to flight computers. Once software has been allocated to a computer, that computer can be selected and expanded to access the subsystem decision tree for the specification of application functionality. The decision model root screen is shown in Figure 5.

FIGURE 5 RSAS DECISION MODEL ROOT SCREEN

The decision model root screen is the starting point for the user to select and tailor decisions for domain subsystems. The top section of the user screen displays the current context for user decisions. For each selected subsystem, the user is guided through a decision-making process that results in the later adaptation of reusable components for a specific application instantiation. Decisions at the subsystem level can be constrained by information provided in the Mission and/or Platform Editors, or be dependent on user decisions in other subsystems. In the RSAS framework, the user identifies spacecraft subsystem functionality and the implementing algorithms. Decisions made by users increase in detail to a point where algorithm configuration parameters are specified (see Figure 6).

FIGURE 6 EXAMPLE OF A DECISION MODEL PARAMETER SCREEN

The RSAS Workbench permits the user to add personal software modules to the instantiation of applications. (It is assumed these modules conform to the domain architecture.) This feature adds flexibility during application engineering to accommodate changes in domain technology. Once decisions have been completed, the user returns to the Platform Editor from which the Component Generation screen (Figure 7) is accessed.

category	destination_label
<input checked="" type="checkbox"/> Code specification	/denal13/RSAS_work/tmp/src
<input checked="" type="checkbox"/> Code body	/denal13/RSAS_work/tmp/src
<input checked="" type="checkbox"/> Requirements	/denal13/RSAS_work/tmp/req
<input checked="" type="checkbox"/> Design	/denal13/RSAS_work/tmp/design
<input checked="" type="checkbox"/> Test cases	/denal13/RSAS_work/tmp/test
<input checked="" type="checkbox"/> Test descriptions	/denal13/RSAS_work/tmp/test
<input checked="" type="checkbox"/> Test software	/denal13/RSAS_work/tmp/test

code module type	tag	extension
Specification		.ads
Body		.adb

Target type

☐ Embedded processor

☒ Simulation on host

Generate

Status

generating files in the CODE_SPECIFICATION category
generating file: /denal13/RSAS_work/tmp/src/host_spacecraf

FIGURE 7 RSAS COMPONENT GENERATION SCREEN

In the Component Generation screen, the user selects the categories of reusable assets that are to be output. For the flight software domain, output options include the production of code for a target processor or a simulation environment in which the code may contain statements to support error detection needs. Figure 8 illustrates the Workbench session process flow for the current implementation within the spacecraft flight software domain.

3

1

Constituents of the Workbench host environment are listed in Table 3.

TABLE 3 WORKBENCH HOST ENVIRONMENT

Development	Operational	
<u>Software</u> GNAT Ada compiler version 3.09 PRO*C pre-compiler (ORACLE product) UIM/X GUI builder version 2.9 Motif developer kit FileMaker Pro 3.0 (optional)	<u>Hardware</u> Sun SPARC station 2 32 Mbytes RAM 100 Mbytes disk space Color Terminal	<u>Software</u> Solaris 2.5 or 2.5.1 CDE (Common Desktop Environment) Netscape Navigator (WWW Server Optional) Shared Libraries (suggested) libMrm.so.3 libXm.so.3 libXt.so.5.0 libX11.so.5.0 libm.so.1 libc.so.1 TRF-2 Access To Oracle Database (via SQL*NET) Oracle Product Version at least 7.0.16

Summary

This report has provided an overview of the application engineering Workbench developed by Lockheed Martin Astronautics under contract to the AFRL Space Vehicles Directorate. The Workbench was developed successfully on a contract that had as its primary objective the creation of an application engineering tool for the spacecraft flight software domain. It incorporates a domain decision model that is used to determine the selection and possible tailoring of reusable components for the instantiation of domain applications. Workbench users specify application attributes via a graphical interface. They are assisted by context-sensitive on-line help information that is available through a Web browser such as Netscape®.

Although the Workbench was developed to simplify and automate the reuse of spacecraft flight software, it facilitates application engineering in any product-line environment where the reuse of assets is governed by a complex decision-making process. It can be adapted for non-spacecraft applications where domain engineering tasks have been completed. The Workbench is installed at the AFRL Space Vehicles Directorate as well as at LMA in Denver and LMMS in Sunnyvale.

DISTRIBUTION LIST

AUL/LSE Bldg 1405 - 600 Chennault Circle Maxwell AFB, AL 36112-6424	1 cy
DTIC/OCP 8725 John J. Kingman Rd, Suite 0944 Ft Belvoir, VA 22060-6218	2 cys
AFSAA/SAI 1580 Air Force Pentagon Washington, DC 20330-1580	1 cy
AFRL/PSOTL Kirtland AFB, NM 87117-5776	2 cys
AFRL/PSOTH Kirtland AFB, NM 87117-5776	1 cy
Lockheed Martin Corporation Lockheed Martin Astronautics P.O. Box 179 Denver, CO 80201-0179	1 cy
AFRL/VS/Dr Fender Kirtland AFB, NM 87117-5776	1 cy
Official Record Copy AFRL/VSSS/Ross H. Wainwright	2 cys